PROBING EUROPA'S INTERIOR WITH NATURAL SOUND SOURCES. Nicholas C. Makris, *Massachusetts Institute of Technology, Cambridge, MA 02139, USA, (makris@mit.edu)*, Sunwoong Lee, *Massachusetts Institute of Technology, Cambridge, MA 02139, USA*, Robert T. Pappalardo, *University of Colorado, Boulder, CO 80309-0392, USA.*

The exploration of Jupiter's icy moon Europa is of paramount interest to astrobiology. Since Europa may harbor a vast liquid ocean below the surface, it is considered one of the most likely places in the solar system for extraterrestrial life to exist. However, there is still no conclusive evidence that a subsurface ocean exists on Europa, and great uncertainties remain on the thickness of the outer ice shell and depth of the potential ocean. Seismo-acoustic surveys are necessary techniques to provide ground truth information on these substantial uncertainties.

Our goal is to use both seismo-acoustic echo-sounding and tomographic techniques to determine Europa's interior structure. Echo-sounding reveals the depth and composition of terrestrial seafloor and sub-bottom layers by analysis of the arrival time and amplitude of acoustic reflections from these interfaces. Tomography reveals the temperature structure of terrestrial oceans by the way sound waves are perturbed along forward propagation paths. We plan to exploit natural cracking events on Europa's surfaces as sound sources of opportunity. Recent work shows that cycloidal cracks on the surface of Europa likely form on a daily basis due to stresses induced by Europa's eccentric orbit which has a period of roughly 3.5 days [1]. We estimate that the acoustic waves radiated from these cracks will be in the $0.1 \sim 100$ Hz range with typical wavelengths exceeding 1 km. In contrast to ice-penetrating radar, such long wavelength disturbances suffer minimal attenuation from mechanical relaxation mechanisms in ice an water and are relatively insensitive to anomalies such as ice fractures. Meteor impacts typically occur at a monthly rate and also have potential use as sound sources.

The Jupiter Icy Moons Orbiter may carry a triaxial seismometer capable of measuring seismo-acoustic displacements in three spatial dimensions at a single point on Europa's surface. Many valuable measurements can be made with a single seismometer. For example, an initial task for this sensor would be to determine the overall level of seismo-acoustic activity on Europa by time series and spectral analysis [2]. This would provide a simple and direct method for determining the level of current surface activity. Correlations could be made of ambient noise versus environmental stress level to determine whether noise levels respond directly to orbital eccentricities. Such an analysis was conducted for the Earth's Arctic Ocean where roughly two meters of nearly continuous pack ice cover an ocean that is typically between $0.1 \sim 5$ km in depth. These terrestrial results show a near perfect correlation between underwater noise level and environmental stresses and moments applied to the ice sheet from wind, current, and drift [3]. Additionally, in the Antarctic, tidally driven ice cracking events and the subsequent tidally driven opening and closing motion of these cracks have long been incidentally observed in ice shelves, and the level of seismicity due to tidally induced ice-fracturing events are shown to be strongly correlated with the sea tides [4, 5].

Robust estimates can be made of Europa's ice layering structure and potential ocean depth with a single acoustic sensor if the signal-to-noise ratio is sufficiently high [2]. On Europa, an isolated cracking event from a cycloidal feature will lead to numerous echoes emanating from multiple reflections of compressional, shear and combined compressional-shear waves from the various layers of Europa's ice-water interior. Using 3-D seismo-acoustic propagation models developed for the Arctic Ocean on Earth, we find that the spacing of arrivals in time can be used to robustly estimate source range as well as ice and ocean layering parameters. To investigate signal-to-noise ratio issues, we have developed a Europan waveguide noise model that is based on classical ocean acoustic noise models [2, 6]. Our present simulations indicate that possible "Big Bang" cracking events lead by the interplay of diurnal stresses with inhomogeneities in the outer ice shell or Europa's potential asynchronous rotation due to an ocean layer below will emanate significant amount of seismo-acoustic waves that can stand robustly above Europan ambient noise. We also show that impacts of even small meteors fall into the Big Bang category that may be frequent enough to be used as sources of opportunity.

The regions in which ice faulting are active can be identified with multiple sensors. The identification of active faulting regions are especially important to astrobiological studies on Europa since faults provide a rapid mechanism for transport of materials from the surface to the ocean and vice-versa. These active regions could form potential habitats for life since the transport of materials may provide necessary ingredients for life. Seismo-acoustic measurements can identify and localize these active faulting regions without ambiguity.

References

[1] Hoppa, G. V., Tufts, R., Greenberg, R., Geissler, P. E., 1999, *Science*, **285**, 1899-1902.

[2] Lee, S., Zanolin, M., Thode, A. M., Pappalardo, R. T., Makris, N. C., 2003, *Icarus*, **165**, 144-167.

[3] Makris, N. C., Dyer, I., 1986, *J. Acoust. Soc. Am.*, **79**, 1434-1440.

[4] Robin, G., 1958, Glaciology III, Norsk Polarinstitut, Oslo.

[5] Anandakrishnan, S., Alley, R. B., 1997, *J. Geophy. Res.*, **102**, 15183-15196.

[6] Kuperman, W. A, Ingenito, F., 1980, *J. Acoust. Soc. Am.*, **67**, 1988-1996.